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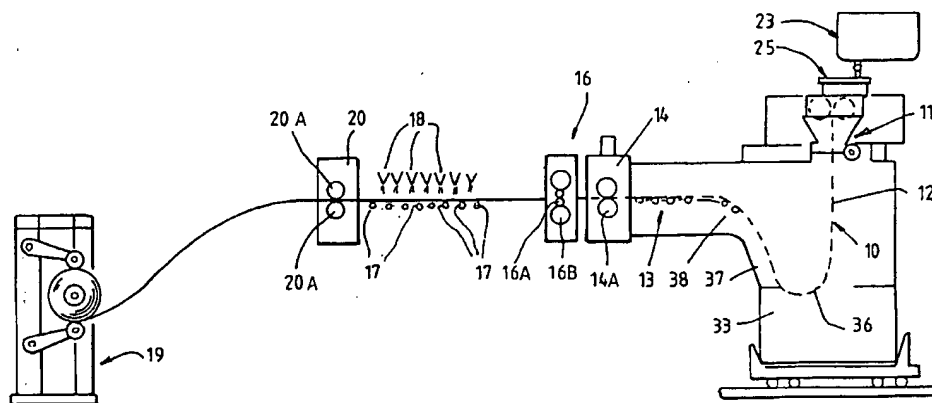
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(54) Title: A METHOD OF PRODUCING STEEL



(57) Abstract: Steel strips and methods for producing steel strips are provided. In an illustrated embodiment, a method includes continuously casting molten low carbon steel into a strip of no more than 5 mm thickness having austenite grains that are coarse grains of 100-300 micron width; and providing desired yield strength in the cast strip by cooling the strip to transform the austenite grains to ferrite in a temperature range between 850 °C and 400 °C at a selected cooling rate of at least 0.01 °C/sec to produce a microstructure that provides a strip having a yield strength of at least 200 MPa. The low carbon steel produced desired microstructure.

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A METHOD OF PRODUCING STEEL STRIP

This application claims priority to Australian Patent Application No. PR0479, filed September 29, 2000.

5

Background and Summary of the Invention

The present invention relates to a method of producing steel strip and the cast steel strip produced according to the method.

10

In particular, the present invention relates to producing steel strip in a continuous strip caster.

The term "strip" as used in the specification is to be understood to mean a product of 5mm thickness or less.

The applicant has carried out extensive research and development work in the field of casting steel strip in a continuous strip caster in the form of a twin roll caster.

In general terms, casting steel strip continuously in a twin roll caster involves introducing molten steel between a pair of contra-rotated horizontal casting rolls which are internally water cooled so that metal shells solidify on the moving rolls surfaces and are brought together at the nip between them to produce a solidified strip delivered downwardly from the nip between the rolls, the term "nip" being used to refer to the general region at which the rolls are closest together. The molten metal may be poured from a ladle into a smaller vessel from which it flows through a metal delivery nozzle located above the nip so as to direct it into the nip between the rolls, so forming a casting pool of molten metal supported on the casting surfaces of the rolls immediately above the nip and extending along the length

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of the nip. This casting pool is usually confined between side plates or dams held in sliding engagement with end surfaces of the rolls so as to dam the two ends of the casting pool against outflow, although alternative means
5 such as electromagnetic barriers have also been proposed. The casting of steel strip in twin roll casters of this kind is for example described in United States Patents 5,184,668, 5,277,243 and 5,934,359.

10 Steel strip is produced of a given composition that has a wide range of microstructures, and therefore a wide range of yield strengths, by continuously casting the strip and thereafter selectively cooling the strip to transform the strip from austenite to ferrite in a
15 temperature range between 850°C and 400°C. It is understood that the transformation range is within the range between 850°C and 400°C and not that entire temperature range. The precise transformation temperature range will vary with the chemistry of the steel
20 composition and processing characteristics.

Specifically, from work carried out on low carbon steel, including low carbon steel that has been silicon/manganese killed or aluminum killed, it has been
25 determined that selecting cooling rates in the range of 0.01°C/sec to greater than 100°C/sec to transform the strip from austenite to ferrite in a temperature range between 850°C and 400°C, can produce steel strip that has yield strengths that range from 200 MPa to 700 MPa or greater.
30 This is a significant development since, unlike conventional slab casting/hot rolling processes where chemistry changes are necessary to produce a broad range of properties, it has been determined that the same outcome can be achieved with a single chemistry.

35 Accordingly, there is provided a method of producing steel strip which includes the steps of:

- 5 -

The low carbon steel may be silicon/manganese killed and may have the following composition by weight:

5	Carbon	0.02 - 0.08%
	Manganese	0.30 - 0.80%
	Silicon	0.10 - 0.40%
	Sulphur	0.002 - 0.05%
	Aluminium	less than 0.01%

10

The low carbon steel may be calcium treated aluminum killed and may have the following composition by weight:

15	Carbon	0.02 - 0.08%
	Manganese	0.40% max
	Silicon	0.05% max
	Sulphur	0.002 - 0.05%
	Aluminum	0.05% max

20

The aluminum killed steel may be calcium treated.

The yield strength of aluminum killed steel is generally 20 to 50 MPa lower than that of silicon/manganese killed steel.

25

Illustratively, the cooling rate in step (b) is less than 1°C/sec to produce a microstructure that is predominantly polygonal ferrite and has a yield strength less than 250 MPa.

30

Illustratively, the cooling rate in step (bis) in the range of 1-15°C/sec to produce a microstructure that is a mixture of polygonal ferrite, Widmanstätten ferrite and acicular ferrite and has a yield strength in the range of 250-300 MPa.

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hot rolling step reduces the strip thickness up to 15%.

The cast strip produced in step (a) illustratively has a thickness of no more than 2mm.

5

The coarse austenite grains produced in step (a) of 100-300 micron width have a length dependent on the thickness of the cast strip. Generally, the coarse austenite grains are up to slightly less than one-half the thickness of the strip. For example, for cast strip of 2mm thickness, the coarse austenite grains will be up to about 750 microns in length.

The cast strip produced in step (a) may have austenite grains that are columnar.

15

The upper limit of the cooling rate in step (b) is at least 100°C/sec.

The term "low carbon steel" is understood to be mean steel of the following composition, in weight percent:

20

25

C: 0.02-0.08
Si: 0.5 or less;
Mn: 1.0 or less;
residual/incidental impurities: 1.0 or less; and
Fe: balance

The term "residual/incidental impurities" covers levels of elements, such as copper, tin, zinc, nickel, chromium, and molybdenum, that may be present in relatively small amounts, not as a consequence of specific additions of these elements but as a consequence of standard steel making. By way of example, the elements may be present as a result of using scrap steel to produce low carbon steel.

30

35

- 5 -

The low carbon steel may be silicon/manganese killed and may have the following composition by weight:

5	Carbon	0.02 - 0.08%
	Manganese	0.30 - 0.80%
	Silicon	0.10 - 0.40%
	Sulphur	0.002 - 0.05%
	Aluminium	less than 0.01%

10

The low carbon steel may be calcium treated aluminum killed and may have the following composition by weight:

15	Carbon	0.02 - 0.08%
	Manganese	0.40% max
	Silicon	0.05% max
	Sulphur	0.002 - 0.05%
	Aluminum	0.05% max

20

The aluminum killed steel may be calcium treated.

The yield strength of aluminum killed steel is generally 20 to 50 MPa lower than that of
25 silicon/manganese killed steel.

Illustratively, the cooling rate in step (b) is less than 1°C/sec to produce a microstructure that is predominantly polygonal ferrite and has a yield strength
30 less than 250 MPa.

Illustratively, the cooling rate in step (bis) in the range of 1-15°C/sec to produce a microstructure that is a mixture of polygonal ferrite, Widmanstatten ferrite and
35 acicular ferrite and has a yield strength in the range of 250-300 MPa.

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Illustratively, the cooling rate in step (bis in the range of 15-100°C/sec to produce a microstructure that is a mixture of polygonal ferrite, bainite and martensite and has a yield strength in the range of 300-450 MPa.

5

Illustratively, the cooling rate in step (b) is at least 100°C/sec to produce a microstructure that is a mixture of polygonal ferrite, bainite and martensite and has a yield strength at least 450 MPa.

10

The continuous caster may be a twin roll caster.

There is provided a low carbon steel produced by the method described above having desired microstructure and yield strength.

15

Brief Description of the Drawings

In order that the invention may be more fully explained, an example will be described with reference to the accompanying drawings, of which:

20

Figure 1 illustrates a strip casting installation incorporating an in-line hot rolling mill and coiler; and

25

Figure 2 illustrates details of the twin roll strip caster; and

Figures 3(a) to 3(d) are photomicrographs of cast strip that illustrate the effect on final microstructure of cooling rates during the austenite to ferrite transformation temperature range.

30

Detailed Description of the Invention

35

The following description of the described embodiments is in the context of continuous casting steel strip using a twin roll caster. The present invention is

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not limited to the use of twin roll casters and extends to other types of continuous strip casters.

Figure 1 illustrates successive parts of a
5 production line whereby steel strip can be produced in
accordance with the present invention. Figures 1 and 2
illustrate a twin roll caster denoted generally as 11
which produces a cast steel strip 12 that passes in a
transit path 10 across a guide table 13 to a pinch roll
10 stand 14 comprising pinch rolls 14A. Immediately after
exiting the pinch roll stand 14, the strip passes into a
hot rolling mill 16 comprising a pair of reduction rolls
16A and backing rolls 16B by in which it is hot rolled to
reduce its thickness. The rolled strip passes onto a run-
15 out table 17 on which it may be cooled by convection by
contact with water supplied via water jets 18 (or other
suitable means) and by radiation. The rolled strip then
passes through a pinch roll stand 20 comprising a pair of
pinch rolls 20A and thence to a coiler 19. Final cooling
20 (if necessary) of the strip takes place on the coiler.

As shown in Figure 2, twin roll caster 11
comprises a main machine frame 21 which supports a pair of
parallel casting rolls 22 having a casting surfaces 22A.
25 Molten metal is supplied during a casting operation from a
ladle (not shown) to a tundish 23, through a refractory
shroud 24 to a distributor 25 and thence through a metal
delivery nozzle 26 into the nip 27 between the casting
rolls 22. Molten metal thus delivered to the nip 27 forms
30 a pool 30 above the nip and this pool is confined at the
ends of the rolls by a pair of side closure dams or plates
28 which are applied to the ends of the rolls by a pair of
thrusters (not shown) comprising hydraulic cylinder units
connected to the side plate holders. The upper surface of
35 pool 30 (generally referred to as the "meniscus" level)
may rise above the lower end of the delivery nozzle so
that the lower end of the delivery nozzle is immersed

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within this pool.

Casting rolls 22 are water cooled so that shells solidify on the moving roll surfaces and are brought
5 together at the nip 27 between them to produce the solidified strip 12 which is delivered downwardly from the nip between the rolls.

The twin roll caster may be of the kind which is
10 illustrated and described in some detail in United States Patents 5,184,668 and 5,277,243 or United States Patent 5,488,988 and reference may be made to those patents for appropriate constructional details which form no part of the present invention.

15 The above-described twin roll caster continuously casts strip 12 of no less than 2mm thickness with a microstructure of columnar austenite grains of 100-300 micron width.

20 In accordance with the illustrated embodiment of the method described, the cooling rate of the cast strip to transform the strip from austenite to ferrite in a temperature range between 850°C and 400°C is selected to
25 control transformation of austenite into a ferrite microstructure that is required to provide specified yield strength of the cast strip.

In accordance with the illustrated embodiment,
30 the cooling rate is at least 0.01°C/sec and may be in excess of 100°C/sec and is selected to transform the steel strip from austenite to ferrite until austenite transformation is completed.

35 In the case of low carbon steels, such a range of microstructures can produce yield strengths in the range of 200 MPa to in excess of 700 MPa.

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With such cooling rates for low carbon steel it is possible to produce cast strip having microstructures including:

5

(i) predominantly polygonal ferrite;

10

(ii) a mixture of polygonal ferrite and low temperature transformation products, such as a Widmanstätten ferrite, acicular ferrite, and bainite; and

15

(iii) predominantly low temperature transformation products.

In the case of low carbon steels, such a range of microstructures can produce yield strengths in the range of 200 MPa to in excess of 700 MPa.

20

The present disclosure is based in part on experimental work carried out on silicon/manganese killed low carbon steel.

25

The table set out below summarises the effect of cooling rate to transform the strip from austenite to ferrite in a temperature range between 850°C and 400°C on the microstructure and resultant yield strength of silicon/manganese killed low carbon steel strip. The strips were cast in a twin roll caster of the type described above.

30

Cooling Rate (°C/sec)	Coiling Temperature (°C)	Microstructure Constituents	Yield Strength (MPa)
0.1	>800	Polygonal ferrite, Pearlite	210
13	670	Polygonal ferrite, Widmanstätten ferrite, acicular	320

- 10 -

		ferrite	
25	580	Polygonal ferrite, Bainite	390
100	<400	Polygonal ferrite, Bainite, Martensite	490

Figures 3(a) to 3 (d) are photomicrographs of the final microstructure of the cast strip.

5 It is clear from the table and the photomicrographs that selection and control of the cooling rate had a significant impact on the microstructure and yield strength of the single chemistry cast strip. As noted above, in conventional slab casting/hot rolling
10 processes, a range of different chemistries would be required to achieve the range of yield strength. The range of chemistries was in the past achieved by adding differing amounts of alloys that add considerable cast to the steel production process.

15 Control of the cooling rate to transform the strip from austenite to ferrite in a temperature range between 850°C and 400°C is achieved by controlling cooling on the run-out table 17 and/or the coiler 19 of the strip
20 casting installation.

 The production of soft materials (yield strength < 350 MPa) requires relatively slow cooling rates through the austenite to ferrite transformation temperature range.
25 In order to achieve the slow cooling rates, it is necessary to complete austenite transformation on the coiler 19.

 The production of harder materials (yield
30 strength > 400 MPa) requires higher cooling rates to transform the strip from austenite to ferrite in a temperature range between 850°C and 400°C. In order to

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achieve the higher cooling rates the austenite transformation is completed on the run-out table.

5 Figures 3(a) to (d) are photomicrographs of the final microstructures of the cast strip.

10 Although the invention has been illustrated and described in detail in the foregoing drawings and description with reference to several embodiments, it should be understood that the description is illustrative and not restrictive in character, and that the invention is not limited to the disclosed embodiments. Rather, the present invention covers all variations, modifications and equivalent structures that come within the scope and
15 spirit of the invention. Additional features of the invention will become apparent to those skilled in the art upon consideration of the detailed description, which exemplifies the best mode of carrying out the invention as presently perceived. Many modifications may be made to
20 the present invention as described above without departing from the spirit and scope of the invention.

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CLAIMS:

1. A method of producing steel strip including the steps of:
- 5
- (a) continuously casting molten low carbon steel into a strip of no more than 5mm thickness having austenite grains that are coarse grains of 100-300 micron width; and
- 10
- (b) providing desired yield strength in the cast strip by cooling the strip to transform the austenite grains to ferrite in a temperature range between 850°C and
- 15
- 400°C at a selected cooling rate of at least 0.01°C/sec to produce a microstructure that provides a strip having a yield strength of at least 200 MPa.
- 20
2. The method of in claim 1 wherein the cast strip produced in step (a) has a thickness of no more than 2mm.
3. The method of in claim 1 or claim 2 wherein the austenite grains produced in step (a) are columnar.
- 25
4. The method of any one of the preceding claims wherein the cooling rate in step (b) is at least 100°C/sec.
5. The method of any one of the preceding claims
- 30
- wherein the low carbon steel is silicon/manganese killed.
6. The method of any one of the preceding claims wherein the silicon/manganese killed low carbon steel has the following composition by weight:

35

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	Carbon	0.02 - 0.08%
	Manganese	0.30 - 0.80%
	Silicon	0.10 - 0.40%
	Sulphur	0.002 - 0.05%
5	Aluminium	less than 0.01%

7. The method of any one of claims 1 to 4 wherein the low carbon steel is aluminum killed.

10 8. The method of claim 7 wherein the aluminum killed low carbon steel has the following composition by weight:

	Carbon	0.02 - 0.08%
	Manganese	0.40% max
15	Silicon	0.05% max
	Sulphur	0.002 - 0.05%
	Aluminum	0.05% max

20 9. The method of any one of the preceding claims wherein the cooling rate in step (b) is less than 1°C/sec to produce a microstructure that has a yield strength in the range of 200-250 MPa.

25 10. The method of any one of claims 1 to 8 wherein the cooling rate in step (b) is in the range of 1-15°C/sec to produce a microstructure that has a yield strength in the range of 250-300 MPa.

30 11. The method of any one of claims 1 to 8 wherein the cooling rate in step (b) is in the range of 15-100°C/sec to produce a microstructure that has a yield strength in the range of 300-450 MPa.

35 12. The method of any one of claims 1 to 8 wherein the cooling rate in step (b) is at least 100°C/sec to produce a microstructure that has a yield strength at least 450 MPa.

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13. The method of any one of the preceding claims further includes passing the strip onto a run-out table and step (b) includes controlling cooling of the strip on
5 the run-out table to achieve the selected cooling rate to transform the austenite grains to ferrite in a temperature range between 850°C and 400°C.

14. The method of any one of the preceding claims
10 further includes the step of in-line hot rolling the cast strip produced in step (a) to reduce the strip thickness up to 15%.

15. The method of any one of the preceding claims
15 wherein the continuous casting is done with a twin roll caster.

16. The method of claim 1 wherein the yield strength
20 is 200 MPa to 700 MPa.

17. A low carbon steel produced by a process
including the steps of:

- 25 (a) continuously casting molten low carbon steel into a strip of no more than 5mm thickness with austenite grains that are coarse grains of 100-300 micron width; and
- 30 (b) providing desired mechanical properties in the cast strip by cooling the strip to transform the austenite grains to ferrite in a temperature range from 850°C to 400°C at a selected cooling rate of at least 0.01°C/sec to produce a microstructure that
- 35 provides a strip having a yield strength between 200 and in excess of 700 MPa, the microstructure being selected from the

- 15 -

group including:

- (i) predominantly polygonal ferrite;
- 5 (ii) a mixture of polygonal ferrite and low temperature transformation products; and
- (iii) predominantly low temperature transformation products.
- 10
18. The low carbon steel of in claim 17 wherein the cast strip produced in step (a) has a thickness of no more than 2mm.
- 15
19. The low carbon steel of in claim 17 or claim 18 wherein the austenite grains produced in step (a) are columnar.
- 20 20. The low carbon steel of any one of claims 17 to 19 wherein the cooling rate in step (b) is at least 100°C/sec.
21. The low carbon steel of any one of claims 17 to
- 25 20 wherein the low carbon steel is silicon/manganese killed.
22. The low carbon steel of claim 21 wherein the low carbon steel has the following composition by weight:
- 30
- | | |
|-------------|-----------------|
| Carbon | 0.02 - 0.08% |
| Manganese | 0.30 - 0.80% |
| Silicon | 0.10 - 0.40% |
| Sulphur | 0.002 - 0.05% |
| 35 Aluminum | less than 0.01% |
23. The method of any one of claims 17 to 20 wherein

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the low carbon steel is aluminum killed.

24. The low carbon steel of claim 23 wherein the low carbon steel has the following composition by weight:

5

Carbon	0.02 - 0.08%
Manganese	0.40% max
Silicon	0.05% max
Sulphur	0.002 - 0.05%
Aluminum	0.05% max

10

25. The low carbon steel of any one of claims 17 to 19 wherein the cooling rate in step (b) is less than 1°C/sec in order to produce a microstructure that is predominantly polygonal ferrite and has a yield strength between 200 and 250 MPa.

15

26. The low carbon steel of any one of claims 17 to 19 wherein the cooling rate in step (b) is in the range of 1-15°C/sec in order to produce a microstructure that is a mixture of polygonal ferrite, Widmanstätten ferrite and acicular ferrite and has a yield strength in the range of 250-300 MPa.

20

27. The low carbon steel of any one of claims 17 to 19 wherein the cooling rate in step (b) is in the range of 15-100°C/sec in order to produce a microstructure that is a mixture of polygonal ferrite and bainite and has a yield strength in the range of 300-450 MPa.

25

30

28. The low carbon steel of any one of claims 17 to 19 wherein the cooling rate in step (b) is at least 100°C/sec in order to produce a microstructure that is a mixture of polygonal ferrite, bainite and martensite and has a yield strength of at least 450 MPa.

35

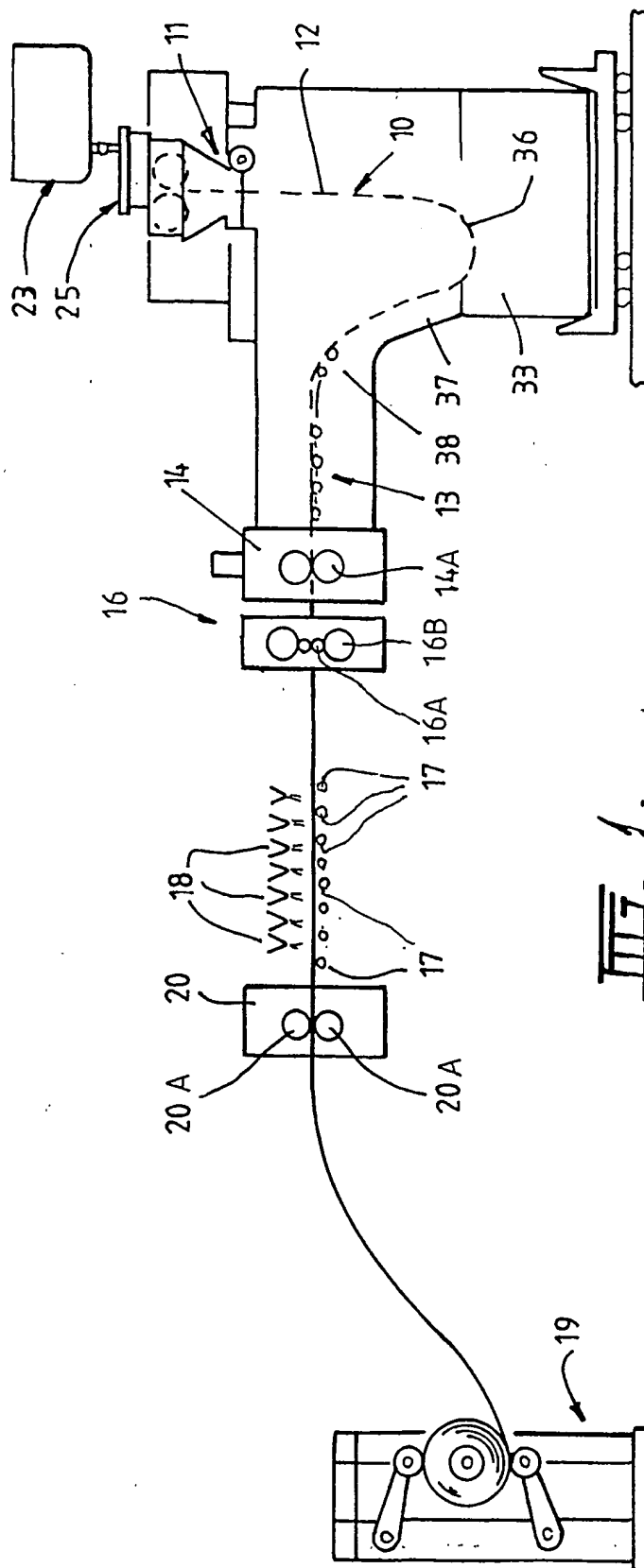
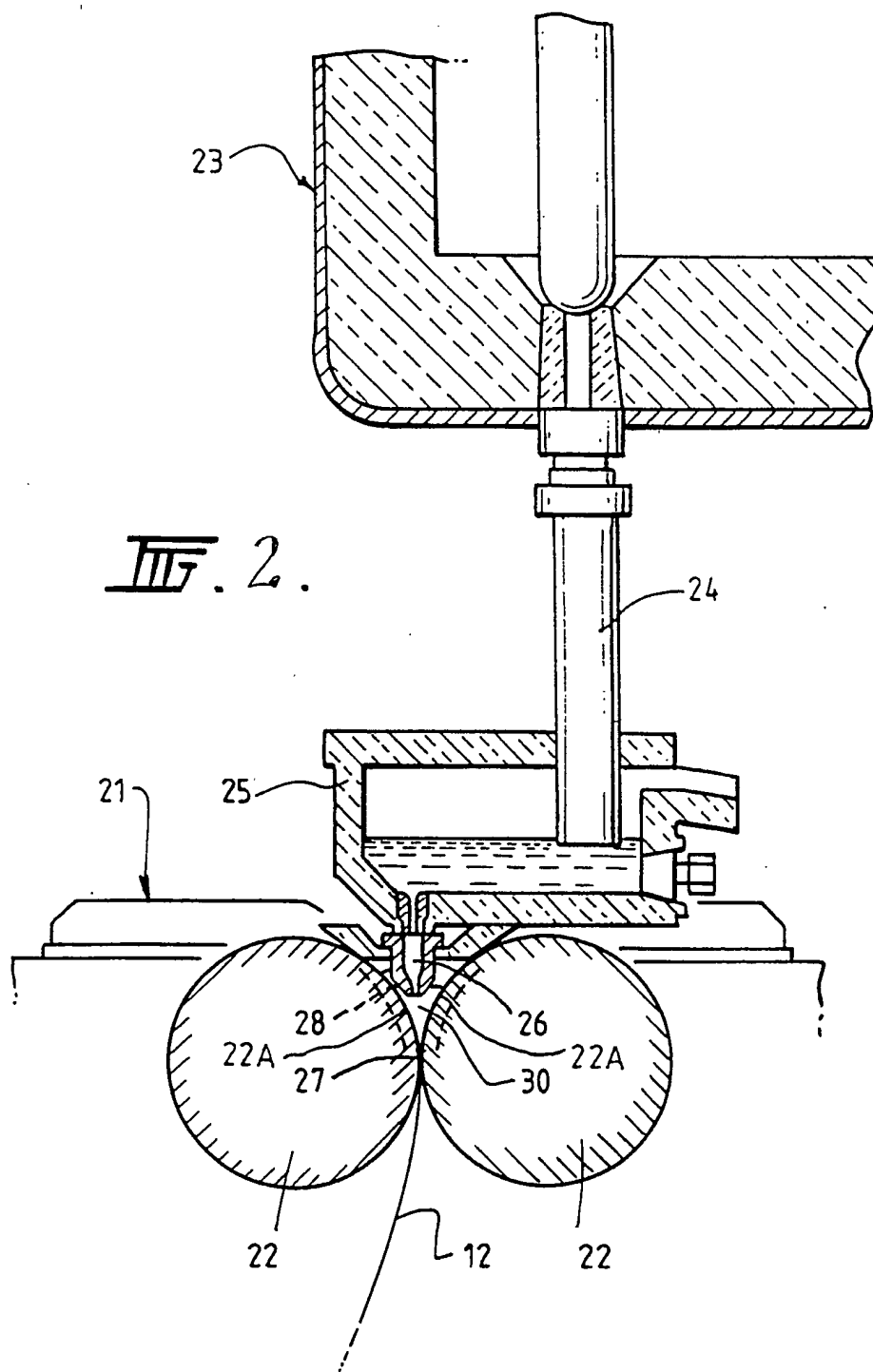


Fig. 1.



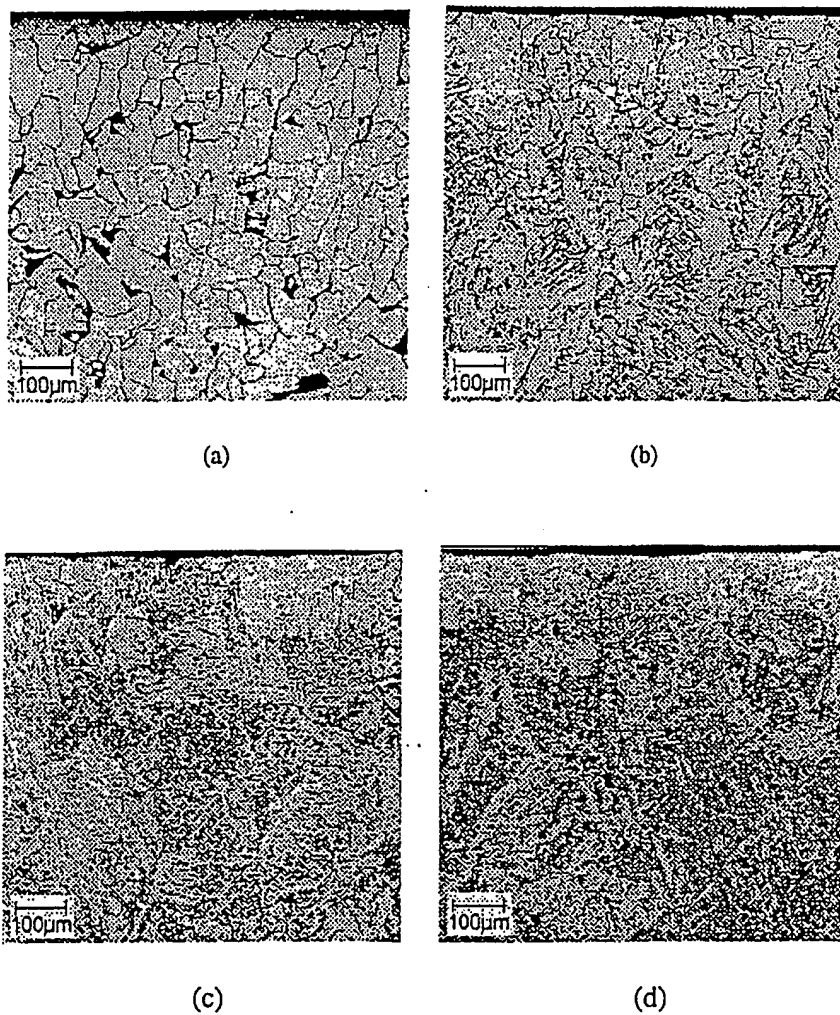


FIGURE 3

INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU01/01215

A. CLASSIFICATION OF SUBJECT MATTER																						
Int. Cl. ⁷ : B22D 11/06, C21D 8/02, 1/00																						
According to International Patent Classification (IPC) or to both national classification and IPC																						
B. FIELDS SEARCHED																						
Minimum documentation searched (classification system followed by classification symbols)																						
IPC: B22D 11/06, C21D 8/02, 1/00																						
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched																						
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)																						
DWPI: FACE(W)CENTERED, FACE(W)CENTRED, GAMMA+, AUSTENIT+, ALPHA, FERRIT+, BODY(W)CENTERED, BODY(W)CENTRED, COOL+																						
C. DOCUMENTS CONSIDERED TO BE RELEVANT																						
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.																				
A	Patent Abstracts of Japan, JP 03-274231 A (NIPPON STEEL CORP) 5 December 1991 whole abstract	1-28																				
A	WO 01/21844 A (USINOR) 29 March 2001 whole document	1-28																				
A	US 6062055 A (BOBIG et al.) 16 May 2000 whole document	1-28																				
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C <input checked="" type="checkbox"/> See patent family annex																						
<p>* Special categories of cited documents:</p> <table border="0"> <tr> <td>"A"</td> <td>document defining the general state of the art which is not considered to be of particular relevance</td> <td>"T"</td> <td>later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</td> </tr> <tr> <td>"E"</td> <td>earlier application or patent but published on or after the international filing date</td> <td>"X"</td> <td>document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</td> </tr> <tr> <td>"L"</td> <td>document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</td> <td>"Y"</td> <td>document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</td> </tr> <tr> <td>"O"</td> <td>document referring to an oral disclosure, use, exhibition or other means</td> <td>"&"</td> <td>document member of the same patent family</td> </tr> <tr> <td>"P"</td> <td>document published prior to the international filing date but later than the priority date claimed</td> <td></td> <td></td> </tr> </table>			"A"	document defining the general state of the art which is not considered to be of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	"E"	earlier application or patent but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family	"P"	document published prior to the international filing date but later than the priority date claimed		
"A"	document defining the general state of the art which is not considered to be of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention																			
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Date of the actual completion of the international search		Date of mailing of the international search report																				
23 November 2001		30 NOV 2001																				
Name and mailing address of the ISA/AU		Authorized officer																				
AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustrialia.gov.au Facsimile No. (02) 6285 3929		B. PREMARATNE Telephone No : (02) 6283 2407																				

INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU01/01215

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2334464 A (KVAERNER METALS CONTINUOUS CASTING LIMITED) 25 August 1999 whole document	1-28
A	WO 98/26882 A (HOOGO VENS STAAL B.V.) 25 June 1998 whole document	1-28
A	WO 95/13155 A (ISHIKAWAJIMA-HARIMA HEAVY INDUSTRIES COMPANY LIMITED) 18 May 1995 whole document	1-28

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/AU01/01215

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report				Patent Family Member			
WO	200121844	FR	2798871				
US	6062055	AU	52768/98	CN	1195584	EP	870553
		JP	10277601				
GB	2334464	EP	937512	JP	11315325		
WO	9826882	AU	53490/98	BR	9714411	CN	1244820
		EP	954392	PL	334211	SK	852/99
WO	9513155	AU	81004/94				
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